Performance comparison of the different IR-UWB receivers in wireless body area networks

Matti Hämäläinen[1], Ville Niemelä[1], Jari Iinatti[1], Ryuji Kohno[1,2]
[1]Centre for Wireless Communications (CWC), University of Oulu, Oulu, Finland
{matti.hamalainen, ville.niemela, jari.iinatti}@ee.oulu.fi
[2]Yokohama National University, Yokohama, Japan
kohno@ynu.ac.jp

Abstract—**This paper gives a performance overview of different types of ultra wideband (UWB) receivers that can be used in wireless body area network (WBAN) applications. The studied receivers are based on both coherent and non-coherent detections. The signal structure is following the IEEE 802.15.4a standard and the channel models used in the simulations are based on the experimental studies carried out at a real hospital environment. Two different links are used; on-body link and a link from body to external access point. Otherwise, the transceiver chain is kept the same all the time to distinguish the differences between studied cases, thus different channels.**

Keywords; wireless body area network, radio channel, healthcare, energy detector, coherent detection, non-coherent detection, medical ICT.

I. INTRODUCTION

A new trend in medical information and communication technology (ICT) is to provide tools for autonomous, secure and robust methods to monitor human's physiological signs with gadgets which can be carried by patients' themselves. Systems should be light, easy to use and wear, and they should also consume very small amount of energy. At the same time, systems need to be very robust and safe due to their medical context. These kinds of apparatuses are expected to come more popular in the forthcoming years. One indication for that is the IEEE 802.15.6 [1],[2] standardization process for wireless body area networks (WBAN). The standard is expected to be frozen and being available during 2011. This standard will determine dedicated signal structures for WBAN use. On the other hand, the standard lets open how to implement receivers.

The other standards that can be used in WBAN communications are existing IEEE 802.15.4 and 4a [3],[4], which determine specifications for low data rate applications for wireless personal area network (WPAN). An amendment IEEE 802.15.4a [4] offers new options for IEEE 802.15.4, such as higher data rates, mobility and precision ranging. The coverage area on WPAN is 10's of meters whereas WBAN is targeted for few meters only. Some examples of exploitation of wireless WBAN technologies are introduced, e.g., in [5].

In this paper, the performances of different types of UWB receivers are compared with the results obtained from computer simulations. The signal structure used in the simulations is following the existing IEEE 802.15.4a standard [4]. The implemented channel models are based on the WBAN channel measurements carried out at the real hospital environment in Oulu, Finland [6],[7]. In addition to the channel models used here, there are, e.g., IEEE 802.15.6 models available [8]. Other WBAN related channel models can be found, e.g., from [9] for in-on-body communications and from [10]-[12] for on-body communications. However, more accurate models for on-body WBAN use in hospital environment are those presented at [6],[7], as expressed in [13].

Due to the variety of applications that WBAN network can support, the final transceiver implementation can vary. In some applications, simple receiver with lower performance can be accepted. On the other hand, some applications require reasonable high data rates and good, reliable throughput, which means that more sophisticated receivers are needed. Depending on the physiological signal to be measured, its importance can also differ, which calls for some prioritizing method to be obtained. Simple sensors, such as measuring body temperature, are sending with low data rates, less than 100 bps, whereas electrocardiogram (ECG) with 12 leads requires a total data rate around 6 Mbps. This is an example of required flexibility of the WBAN node and network realizations. The performances of different ultra wideband (UWB) WBAN receiver structures have already been studied, e.g., in [14]-[16]. Within those papers, the performances are studied for on-body WBAN links. This paper extends the earlier research and shows comparative analysis of the WBAN receiver performances using two different links involved in the communications; on-body channel (WBAN) and off-body channel (WPAN), both using the same transceiver implementations.

The rest of the paper is organized as follows. The second chapter introduces the receiver structures and channel models used in the study. Chapter three summaries the results and the last chapter concludes the work.

II. RECEIVERS AND CHANNELS

The architecture for medical ICT communication should be flexible and scalable so that it can be exploited in various services and environments. The assumed WBAN use is targeted for homes, caring institutions, such as hospitals, elderly homes, etc., and also to be used during transportation. In addition, the communication requirements can be various; starting from a transmission of data originated by implanted or on-body sensor to portable base station, or a communication between WBAN and access points operated, e.g., by an external service provider. Each link in the transmission path could have different physical layer (PHY), quality and load requirements, and so on. From implementation point-of-view, this could mean the use of multi-radio transceivers. However, the target is to keep WBAN transceiver implementation as simple as possible, which means that it is favorable to use the same radio technology in WBAN and WPAN links.

According to the IEEE 802.15.4a standard [4], it is possible to use either coherent or non-coherent impulse radio (IR) based UWB receivers to detect the transmitted signal. Within this study, simple energy detector (ED) and some binary orthogonal receivers are used to detect IR-UWB signal. The applied data modulation techniques are burst position modulation (BPM) and binary phase shift keying (BPSK). Generally, BPSK is intended for carrying convolutional channel coded (CC) bits, but for some options, original information bits can also be modulated with BPSK. The latter procedure doubles the system data rate because one symbol is carrying two information bits; the first bit in the position of the burst within a symbol and the second bit in the phase of the same burst. Reed-Solomon code (RS) is used to encode redundant bits which are added to the tail of the information bit stream, and are always position modulated. By the receiver implementation, the redundant bits can be used at the detection to improve the link performance, or the redundant bits can just be discarded. The information bits in IEEE 802.15.4a are, in general, position modulated by BPM, which makes it possible to utilize simple non-coherent receivers at detection. Table 1 gives a summary of the studied receiver combinations. The mathematics to calculate decision variables in different approaches are shown, e.g., in [14]-[16].

In coherent detection, the locally generated reference signal is utilizing a priori channel information. In the case of ED (Type 1&2), the signal bandwidth is limited using ideal bandpass filter. The impacts of the antennas are included in the channel models, not taken into account at the transceiver chain implementation. This does not limit the generality of the study because the aim here is to make a comparison between the different detection algorithms in WBAN and WPAN channels. The signal models used are following the standard [4]. To get more variability to detection side, all rake (a-rake), selective rake (s-rake) and partial rake (p-rake) receivers are implemented to the Matlab® simulator. Different rake types are discussed, for example, in [17],[18] in more details. At the end, the presented results are distinguishing the performances of different IR-UWB receiver implementations.

The simplest studied receiver is Type 1 energy detector (ED). Type 2 receiver combines the approaches of Type 1 and Type 6 receivers. Firstly, it detects positions modulated bit by ED and then, at the second phase, detects the phase modulated bit. Those bits belong to the same time slot and this leads to detection of two bits within one symbol. This duality improves the performance of Type 1 receiver but worsens significantly the performance of Type 6 receiver, as to be shown later. In Type 6 receiver, the position modulated bit is assumed to be known, and only the phase modulated bit is detected. In receiver Types 4 and 5, similar to Type 2, the detection of the position modulated bit has to be done in a non-coherent manner since the detection of the phase modulated bit of the same burst. Due to the large amount of possible pulse combinations to form a symbol, this study is limited to the mandatory mode of the IEEE 802.15.4a signal structure, having eight time slots available within a frame, allowing eight simultaneous users, 16 pulses each having a pulse width of 2 ns allocated for a symbol, giving a symbol rate of 980 kbps for transmission. The payload data rate is 850 kbps and the rest of the traffic comes from the coding. However, Type 2 and Type 5 receivers, which have not been defined for 980 kbps rate, are included in the results. Type 2 and Type 5 are targeted for symbol rates of 15.6 Mbps and 3.9 Mbps, respectively, and are using only one pulse per burst.

Table 1. Combinations of the studied receiver types

Receiver type	BPM	BPSK	bits/symbol
Type 1	Energy detection	--	1 information bit
Type 2	Energy detection	Coherent	2 information bits
Type 3	Binary orthogonal noncoherent	--	1 information bit
Type 4	Binary orthogonal noncoherent	Coherent / convolutional decoding	1 information bit + 1 convolutional bit
Type 5	Binary orthogonal noncoherent	Coherent	2 information bits
Type 6	Assumed to be known	Coherent	1 information bit

As stated above, the channel models used within this study are based on the measurements carried out at the premises of Oulu University Hospital [6],[7]. All together, the WBAN measurement campaigns covered several environments and scenarios, as presented in Table 2. Two links with different propagation mechanisms have been selected for this study. The links are from a wrist to a chest (WBAN) and about 2 meters link from a chest to a room access point (WPAN). The links are line-of-sight and are depicting standing human posture.

Medical systems operating in very close vicinity of a human body are one special example of wireless networks that can utilize UWB radio. Suitable applications are, for example, ECG, electroencephalography (EEG), and related measurement systems, and they are communicating via WBAN type link. The personal health information is sent ahead via WPAN link, thus through different channel. The average impulse responses over 100 consecutive impulse responses for WBAN and WPAN links, which are used in the simulations, are shown in Figure 1. Summary of the CWC's WBAN radio channel measurement activities can be found from [19].

Although the direct distance from human backside to chest is not long, an UWB signal does not go through the body but circulates over the body surface. In addition, implanted metallic obstacles impact also on close body signal propagation, as showed in [20],[21]. Based on the studies, the main lobe of the measured impulse response is attenuated when a metallic implant is close to communicating antenna. These kind of features need to be taken into account when designing UWB WBAN systems.

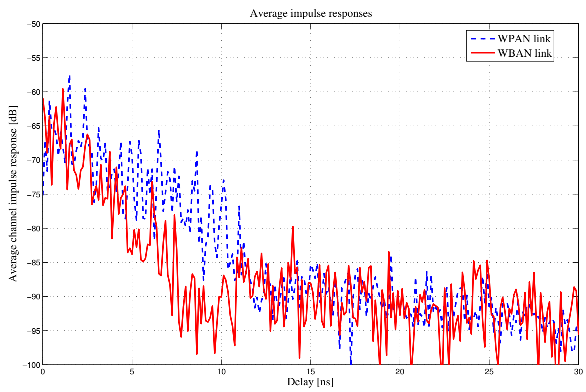

Figure 1. Average impulse responses of WBAN and WPAN channels used in the simulations.

Table 2. Different scenarios for WBAN channel modeling carried out by CWC[1]

Environments	Scenarios				
Anechoic chamber	Standing around the body	standing for WBAN, WPAN	lying for WBAN, WPAN	walking* for WBAN, WPAN	lying with moving arm* WBAN, WPAN
Class room	standing for WBAN, WPAN	sitting for WBAN, WPAN	lying for WBAN, WPAN	-	-
Hospital: regular room (ward)	standing for WBAN, WPAN	lying for WBAN, WPAN	walking* for WBAN, WPAN	lying with moving arm* WBAN, WPAN	-
Hospital: corridor	standing for WBAN, WPAN	walking* for WBAN, WPAN	walking with a drippole* for WBAN, WPAN	-	-
Hospital: surgery room (operation theatre)	lying for WBAN, WPAN with medical devices on	lying for WBAN, WPAN with medical devices off	lying for WBAN, WPAN with medical devices off with people randomly walking	lying for WBAN, WPAN with medical devices off with people randomly walking and using mobile phone	-

III. COMPARATIVE RESULTS

In the simulations, bit error rates (BER) as a function of signal-to-noise-ratio were calculated by sending 1.5 million bits per each E_b/N_0, where E_b states energy of one bit and N_0 is a power spectral density of zero mean white Gaussian noise. The performance of the developed simulator is verified against the theoretical results. Within the following comparisons between the two links, WBAN and WPAN, the system parameters at the transceiver chain have been kept unchanged. The simulations are carried out using the parameters of the mandatory mode of IEEE 802.15.4a but the channel models are based on the measurements at real hospital environment.

In Figures 2 and 3, the a-rake and ED receivers' performances are shown using the WBAN and WPAN channel models for a typical hospital ward (standing posture). As expected, the ED's performance is the worst because it just collects the energy within a certain time frame. The performance decline to the coherent detection (Type 6) is 8 dB to 12 dB at BER level 10^{-3} depending on the channel. Type 5 receiver attained almost the performance of Type 6 receiver. All binary orthogonal receivers will fit within a 5 dB range. The difference between the on-off-body and on-body channels is about 2 dB to the advance of WPAN link. However, if a movement of hand is taken into account, the situation will differ due to the partial non-line-of-sight links within a walking cycle, for example. Body blocking has an impact on both link types, and is depending on the body posture during the communication moment.

The results from s-rake follow the ones of a-rake giving better performance in WPAN channel, as shown in Figures 4 and 5. However, the difference between a-rake and s-rake can be found from the higher E_b/N_0 values, where a-rake utilizes all the signal energy available at the receiver front-end. In the s-rake case, only 5 fingers have been used to collect energy. More comprehensive performance study of s-rake IR-UWB receiver as a function of rake fingers is presented in [16].

In Figure 6, the results of s-rake are shown for receiver types 3, 4 and 6 as a function of rake fingers. E_b/N_0 is fixed to 13 dB. The performance of Type 1 ED receiver is also shown as a reference. In all the studied cases, WPAN link outperforms the WBAN transmission in BER point-of-view. When increasing the number of rake branches, all the performances tend to saturate to certain level which depends on the receiver structure used. The maximum limit of usable rake fingers is around 15 to 20. ED does not utilize information from multiple rake branches and thus its performance remains the same when E_b/N_0 is fixed.

In Figure 7, the corresponding results for p-rake are shown for receiver Types 3, 4 and 6. E_b/N_0 is again fixed to 13 dB and the results for Type 1 receiver are shown as a reference. From the results, it can be seen that now the WBAN channel gives better performance than WPAN channel. The reason can be found from Figure 1, where the average impulse responses for both channels are presented. As a p-rake utilized only the n first paths, it will discard possible stronger paths that are arriving with longer delays. In WBAN case, most of the signal energy is concentrating to smaller delays and thus p-rake performs well. However, the mutual performance order between different receiver structures will remain the same as in the s-rake case. In addition, the performances will saturate, but with higher number of rake fingers than s-rake. Now, the maximum number of fingers which gives improvement to the performance is around 30.

As stated in [16], taking a rake receiver to another environment can denote at the reception point-of-view that the rake receiver needs to select $n+m$ first or strongest arriving signal components for the decision making, instead of the n first or strongest ones. When comparing the influence of the two different links, WBAN and WPAN, the effect is similar even the environment remains the same. In WBAN link, the body is influencing the transmission and the receiver depends more on the first arriving line-of-sight signal cluster than in the case of off-body link. This is an important design parameter in

[1] "*" denotes pseudo-movement

the case when the body access point is at the same time receiving information from an on-body sensor and conveying the same information to a room access point, which is operating with a longer distance than the on-body sensor.

IV. SUMMARY

This paper summarizes the comparative study on performances of different kinds of UWB receivers used in the wireless body area network applications. The studied receivers are based on the IEEE 802.15.4a IR-UWB standard. The results showed that both partial and selective rake receivers can improve their performances according to the added rake fingers. However, maximum amount of fingers to be used is between 10 and 20 in s-rake, and around 20 to 30 in p-rake. After those amounts, the performance is saturating for fixed E_b/N_0. An energy detector gives the worst performance but has the benefit of having a simpler implementation. Selective rake will give the best performance even with the reasonable number of fingers (5-10) in all the studied receiver types and channels. As a conclusion, the same implementation can be used in both WBAN and WPAN cases for reliable communication. However, a difference in the performance, which comes from the channel, can be distinguished. In the case of WBAN link, when the same amount of fingers is used, p-rake will perform better than in WPAN link due to the concentration of the signal energy to shorter delays. S-rake is always utilizing the strongest paths so its performance relates more on the number of receiver branches used than a channel. As a conclusion, it can be noticed that it is possible to utilize IEEE 802.15.4a system in both WBAN and WPAN links, but the coming IEEE 802.15.6 will, hopefully, improve the receiver performances in body area networks because it is targeted for that. More focused corresponding study on IEEE802.15.6 performance is left for future studies.

ACKNOWLEDGEMENTS

This work is partly funded by the Finnish Funding Agency for Technology and Innovation through EWiHS project.

REFERENCES

[1] A. Astrin, et.al., "TG6 Draft," IEEE P802.15-10-0245-06-0006. 2010.

[2] A.W. Astrin, H.-B. Li, R. Kohno, "Standardization for Body Area Networks," IEICE Transactions on Communications E92-B(2): 366-372, 2009.

[3] IEEE Std 802.15.4-2006, "Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)," 2006.

[4] IEEE Std 802.15.4a-2007, "Amendment to 802.15.4-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)," 2007.

[5] M. Hämäläinen, A. Taparugssanagorn, J. Iinatti, R. Kohno, "Exploitation of Wireless Technology in Remote Care Processes," IEICE Transactions on Communications E92-B(2): 373-378, 2009.

[6] A. Taparugssanagorn, C. Pomalaza-Raez, A. Isola, R. Tesi, M. Hämäläinen, J. Iinatti, "UWB channel modelling for wireless body area networks in a hospital," International Journal of Ultra Wideband Communications and Systems 1(4): 226-236, 2010, InderScience Publishers. DOI: 10.1504/IJUWBCS.2010.034304.

[7] A. Taparugssanagorn, C. Pomalaza-Ráez, A. Isola, R. Tesi, M. Hämäläinen, J. Iinatti, "Preliminary UWB Channel Study for Wireless Body Area Networks in Medical Applications," International Journal of Ultra Wideband Communications and Systems 2(1): 14-22, 2011, InderScience Publishers. DOI: 10.1504/IJUWBCS.2011.038632.

[8] IEEE P802.15-08-0780-12-0006, "Channel Model for Body Area Network (BAN)", 2010.

[9] K.Y. Yazdandoost, R. Kohno, "Body Implanted Medical Device Communications," IEICE Transactions on Communications E92-B(2): 410-417, 2009.

[10] N. Katayama, K. Takizawa, T. Aoyagi, J. Takada, H.-B. Li, R. Kohno, "Channel Model on Various Frequency Bands for Wearable Body Area Network," IEICE Transactions on Communications E92-B(2): 418-424, 2009.

[11] B. Zhen, M. Kim, J. Takada, R. Kohno"Characterization and Modeling of Dynamic On-Body Propagation at 4.5 GHz," IEEE Antennas and Wireless Propagation Letters, Vol. 8: 1263-1267, 2010.

[12] T. Aoyagi, K. Takizawa, T. Kobayashi, J. Takada, K Hamaguchi, R. Kohno, "Development of an Implantable WBAN Path-Loss Model for Capsule Endoscopy," IEICE Transactions on Communications E93-B(4): 846-849, 2010.

[13] H. Viittala, M. Hämäläinen, J. Iinatti, A. Taparugssanagorn, "Different experimental WBAN channel models and IEEE802.15.6 models: comparison and effects," in Proc. the 2nd International Symposium on Applied Sciences in Biomedical and Communication Technologies, Bratislava, Slovakia, 2009.

[14] V. Niemelä, A. Rabbachin, A. Taparugssanagorn, M. Hämäläinen, J. Iinatti, "A Comparison of UWB WBAN Receivers in Measured Hospital Environments," in Proc. the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies, Rome, Italy, 2010.

[15] V. Niemelä, J. Iinatti, M. Hämäläinen, A. Taparugssanagorn, "On the Energy Detector, P- and S-Rake Receivers in a Measured UWB Channel Inside a Hospital," in Proc. the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies, Rome, Italy, 2010.

[16] V. Niemelä, M. Hämäläinen, J. Iinatti, A. Taparugssanagorn, "P-Rake Receivers in Different Measured WBAN Hospital Channels," in Proc. the 5th International Symposium on Medical Information and Communication Technology, Montreux, Switzerland, 2011.

[17] M.Z. Win, R.A. Scholtz, "Characterization of ultra-wide bandwidth wireless indoor channels: A communication-theoretic view," IEEE Journal on Selected Areas in Communications 20(9): 1613 – 1627, 2002.

[18] D. Cassioli, M.Z. Win, F. Vatalaro, A. Molisch, "Performance of low-complexity rake reception in a realistic UWB channel," in Proc. IEEE International Conference on Communications, New York, NY, USA, 2002.

[19] M. Hämäläinen, A. Taparugssanagorn, J. Iinatti, "On the WBAN Radio Channel Modelling for Medical Applications," in Proc. the 5th European Conference on Antennas and Propagation, Roma, Italy, 2010.

[20] A. Taparugssanagorn, C. Pomalaza-Raez, A. Isola, R. Tesi, M. Hämäläinen, J. Iinatti, "UWB Channel Modeling for Wireless Body Area Networks in Medical Applications," in Proc. the 4th International Symposium on Medical Information and Communication Technology, Montreal, Canada, 2009.

[21] W.-B. Yang, K. Sayrafian-Pour, J. Hagedorn, J. Terrill, K.Y. Yazdandoost, A. Taparugssanagorn, M. Hämäläinen, J. Iinatti. "Impact of an Aortic Valve Implant on Body Surface UWB Propagation: A Preliminary Study," in Proc. the 5th International Symposium on Medical Information and Communication Technology, Montreux, Switzerland, 2011.

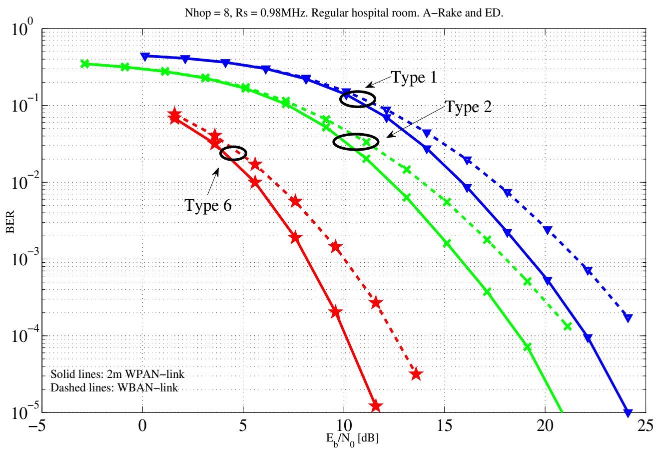

Figure 2. Mandatory mode of IEEE802.15.4a. Energy detectors with receiver Types 1 & 2 and coherent detection Type 6, a-rake.

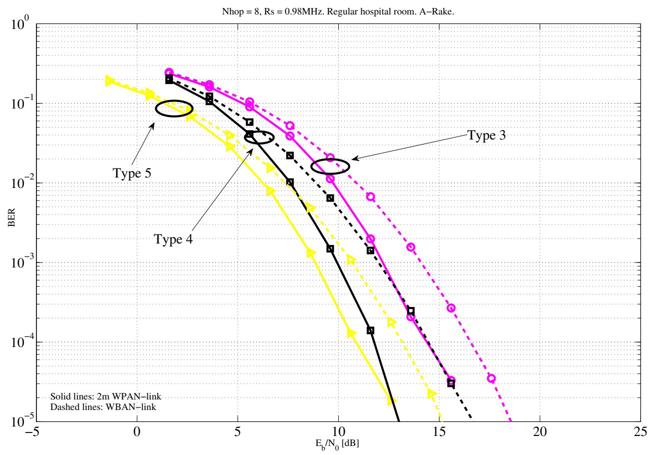

Figure 3. Mandatory mode of IEEE802.15.4a. Binary orthogonal non-coherent detectors, receiver Types 3 & 4 and 5, a-rake.

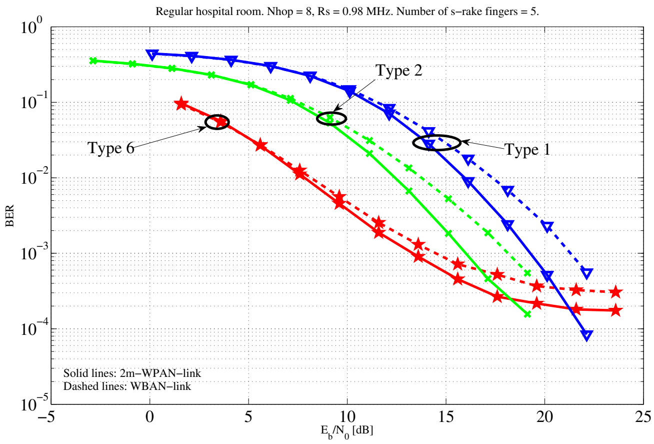

Figure 4. Energy detectors with receiver Types 1 & 2 and coherent detection Type 6 s-rake with 5 fingers.

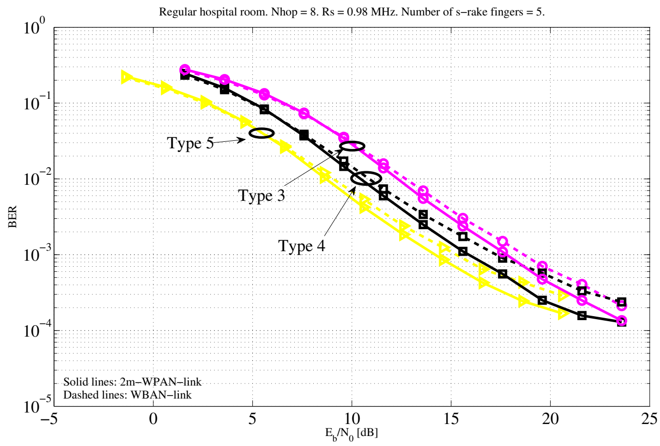

Figure 5. Binary orthogonal non-coherent detectors, s-rake receiver Types 3 & 4 & 5 with 5 fingers.

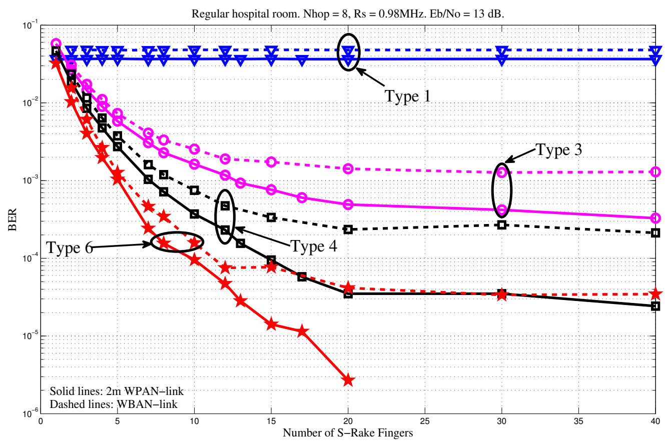

Figure 6. Types 3 & 4 & 6 s-rake receivers with different number of fingers + Type 1 ED receiver. E_b/N_0 is 13 dB.

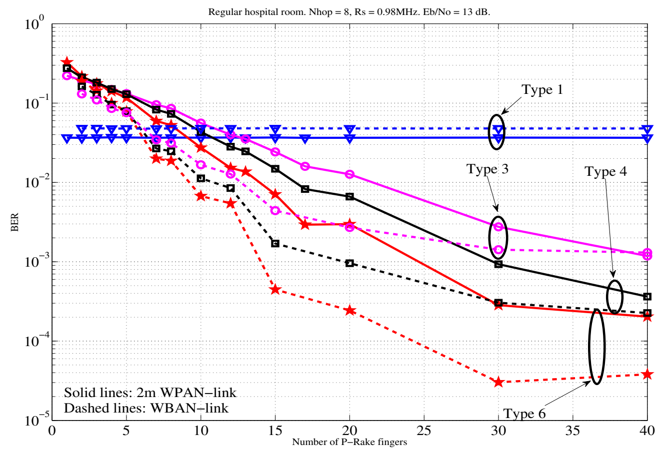

Figure 7. Types 3 & 4 & 6 p-rake receivers with different number of fingers + Type 1 ED receiver. E_b/N_0 is 13 dB.